Wave Breaking and Wave Driven Flow in the Nearshore

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LONG-TERM GOALS

The long-term goals of this research are to understand and model the spatial and temporal transformation of wave breaking in the surf zone of natural beaches, and to predict the effect of wave breaking on the forcing of mean and oscillatory flow, sediment transport, and the evolution of large scale topography.

OBJECTIVES

(1) Improved modeling of wave breaking patterns observed in the surf zone, and the effect of wave breaking on the spatial distribution of mean flow and sediment transport.

(2) Develop Particle Image Velocimetry (PIV) methods to measure surface currents inside and near the surf zone from video imagery of the sea surface.

APPROACH

Understanding wave dissipation in the nearshore is approached through modeling of field observations obtained across a variety of beach profiles and under a wide range of wave conditions. Wave breaking data are obtained remotely from video recordings of the surf zone, and image processing techniques subsequently used to detect and quantify the position and time of wave breaking occurrences over spatial and temporal scales ranging 10-1000 meters and 10-10000 seconds. The observed spatial distribution of ensemble-averaged wave breaking patterns are used - in combination with collaborative measurements of *in situ* wave pressure and velocity - to improve wave dissipation estimates, and subsequently applied to parametric models of incident wave energy transformation, mean current forcing, and sediment transport within the surf zone. This work is being conducted collaboratively Dr.'s E. B. Thornton and T. P. Stanton of the Naval Postgraduate School, and Dr.'s A. E. Hay and A. J. Bowen of Dalhousie University.

The problem of measuring surface currents over a large area of the surf zone is approached through a combination of image processing and PIV software development, and new deployment methods to mount video cameras in a vertically downward orientation upon tethered blimps moored above the surf zone. Software development is being done collaboratively with Dr. J. Shore of Ohio State University.

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WORK COMPLETED

Analysis of video observations of surf zone wave breaking obtained continuously for about 2 months during the 1997 SandyDuck experiment has been completed. The position and time of wave breaking occurrences along seven shore-normal transects, extending from the shoreline to beyond the width of the surf zone, have been determined using automated methods that best distinguish breaking waves and bores from non breaking waves. The observations are used to quantify the spatial and temporal scales of wave breaking distributions on time scales ranging from individual breaking, O(10-*sec*), to single and multiple wave groups, O(0.1-1-*hour*), tides, O(1-*hour*), and changes in the wind and wave conditions, O(1-10-*day*). Simultaneous *in situ* observations of the vertical and horizontal distribution of mean flow were obtained by SandyDuck collaborators, and used in conjunction with the wave breaking observations to model undertow and longshore currents.

Development of the PIV software to determine surface currents from both obliquely and vertically oriented video cameras has begun. Comparisons between video-derived surface currents and *in situ* measurements in the water column during SandyDuck are being pursued.

RESULTS

We have developed empirical algorithms to identify the location of individual breakers in timestack imagery. The precision of identifying the leading edge of the breakers is estimated to be generally 1 pixel. The accuracy in detecting breakers from other non breaking features, such as residual foam left after the passage of a breaking wave, is estimated to be 1-2% of the total breaking waves for most days. The analyzed timestacks are used to compute statistical representations of the breaking wave field.

The breaking frequency can be normalized by the total number of waves obtained from incident wave pressure measured outside the surf zone to yield the fraction of the wave field that is breaking, Q, and used to calibrate ensemble-averaged wave transformation models (Lippmann, *et al.*, 1996). Surface shear stress profiles computed from the wave transformation model are calibrated with observations of Q, and used in the momentum balance to model the generation and variation of set-up (Reniers, *et al.*, 2000), vertical profiles of undertow and mean longshore currents (Garcez Faria, *et al.*, 1998; 2000), and the horizontal distribution of mean longshore currents (Garcez Faria, *et al.*, 2000). This work has verified that inclusion of wave rollers in the energy and momentum balance improves the spatial modeling of the wave forcing. An important result is that bottom drag coefficients used for calculating vertical mean current profiles are consistent with coefficients used for computing horizontal mean flow. Thus, quasi three-dimensional circulation models can be derived from consistent use of the energy and momentum equations (Garcez Faria, *et al.*, 2000).

Surface flow patterns in the surf zone can be quantified using video imagery by interrogating pairs of images separate in time by a small amount. The images are transformed into an ortho-normal plan view using known image-to-ground transformation geometry, and then convolved with a small (order 4 m wide) correlation kernel to determine feature displacements within the area of the kernel. Subsequent filtering operations are performed to remove spurious vectors resulting from poor or noisy correlation matrices. This image analysis methodology is known as Particle Image Velocimetry (PIV; *e.g.*, Raffel, *et al.*, 1998), and is used commonly in laboratory settings to measure, for example, high-frequency velocities in fluid mechanics applications (*e.g.*, Adrian, 1991). In the laboratory experiments, the flow is seeded with particles and illuminated in a plane so that advected particle

displacements can be detected with video or photographic sensors. PIV field techniques for measuring turbulence in the coastal ocean have also been recently developed, in which a water particles (sediment, bubbles, *etc*.) are illuminated and measured with undersea lasers and video cameras (Bertuccioli, *et al.*, 1999). For our application, surface flow can be mapped by observing time series of foam, bubbles, biota, and sediment visible on the water surface, and using PIV techniques to detect advection displacements in a similar manner as the seeded laboratory experiments.

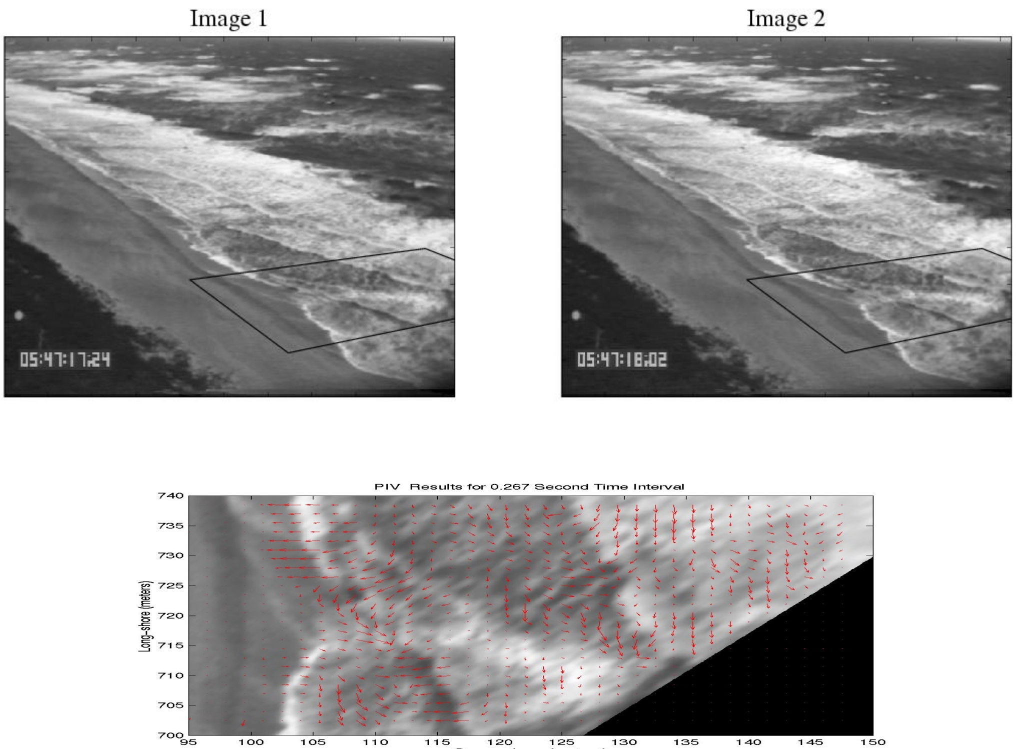

Figure 1. Example PIV analysis of two images obtained from the 1997 SandyDuck experiment. The upper figures show snapshots of wave breaking separated in time by 0.267 seconds (8 video frames). The outlined region is interrogated with over-lapping 2-m wide correlation convolution kernels and subsequent filtering operations. The results of the PIV analysis are shown in the lower panel over-laid on the rectified region outlined in Image 1. The coordinates of the axes are in meters in the SandyDuck coordinate system. The velocity vector magnitudes and directions are consistent with motions qualitatively observed in the video. The maximum vector magnitude is 1.62-m/s for scale.

An example PIV analysis of two high-oblique images obtained from a stormy day during the 1997 SandyDuck experiment is shown in Figure 1. The image pair at the top of the figure was obtained from frames in the same video record separated in time by 0.267 seconds (8 frames of the 30 Hz video). The area defined by the solid lines in each image is rectified into ortho-normal plan view maps and subjected to the PIV analysis. The rectified region from Image 1 is shown in the lower figure with axes in meters relative to the coordinate system at the SandyDuck field site. The surface velocity field obtained from the PIV analysis is indicated by the vectors over-laid on the image. The velocity field is representative of the movement of features visible in each of the images. The small time interval

ensures that most of the features in Image 1 are also in Image 2, allowing for the correlation convolution to detect feature displacements with sub-pixel accuracy. Spurious vectors are removed using three successive filtering operations. The first is a signal-to-noise ratio threshold, determined empirically, that passes only displacements that result from well defined peak correlation's relative to the second highest peak. The second is a global histogram filter, which removes vectors with magnitudes that are outside a defined limitation determined crudely by maximum phase speeds of wave propagation in the image. Finally, a median filter is applied to the results that attempt to remove vectors that are outside a defined range. Although there are a few spurious vectors that make it through the filtering operations, the resulting vector field has magnitudes (maximum velocities of 1.62 m/sec) and directions consistent with the visually observed pattern apparent in the video record.

Difficulties arise in the PIV analysis when the resolution of the image is poor. High-oblique views typical of SandyDuck and other past experiments do not provide adequate resolution of image pixels over a large extent of the surf zone. Thus, analysis from these data are restricted to regions close to shore and near the camera (as shown in Figure 1). To accurately resolve the flow over a large extent of the surf zone a new camera mounting platform is under development. Our strategy is to mount video cameras directly over the surf zone using a tethered blimp elevated to an altitude of about 400-500 feet, high enough to image the entire surf zone width and span approximately 400-500 m of beach. The blimp will be equipped with differential GPS receiver, inclinometer, and compass to ensure accurate image-to-ground transformation with high pixel resolution over the extent of the surf zone.

IMPACT/APPLICATIONS

Improvements in the sampling and modeling of wave breaking have lead to improved models for ensemble-averaged wave transformation and the forcing for mean flow. Development of new remote sensing methods for measuring surface currents over large areas of the surf zone can be used to verify circulation models in the nearshore where *in situ* instrumentation is difficult to deploy.

TRANSITIONS

Observations of wave breaking are being utilized by SandyDuck collaborators to model wave transformation, mean currents, void fraction, and sediment suspension in the surf zone.

RELATED PROJECTS

Video data analysis of the 1990 Delilah, 1994 Duck94, 1996 MBBE, and 1997 SandyDuck experiments have been examined in collaboration with other ONR-funded scientists making *in situ* observations of wave and current properties, turbulence, sediment suspension, large and small scale bathymetry, and bubble properties and void fraction.

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